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SAN FRANCISCO

SPECIAL REPORT 1-B

DECEMBER 1950

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# THE CALERA LIMESTONE

## IN SAN MATEO AND SANTA CLARA COUNTIES, CALIFORNIA

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# THE CALERA LIMESTONE IN SAN MATEO AND SANTA CLARA COUNTIES, CALIFORNIA \*

By GEORGE W. WALKER \*\*

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## ABSTRACT

The principal limestone quarries in the central and southern San Francisco Peninsula area of the Coast Ranges are in discontinuous faulted segments of a single stratigraphic unit, the Calera limestone. This discontinuous zone of limestone outcrops extends southeastward from Calera Valley in San Mateo County through the large quarries of the Permanente Cement Company near Monte Vista, Santa Clara County (pl. 1) and probably tens of miles beyond. The zone strikes N. 45° W., obliquely across the dominant faults, which strike N. 10°-40° W. The cross-cutting relationship of the limestone zone to the faults accounts not only for the discontinuity of limestone masses within the zone, but also for much of the crushed and broken character of the limestone.

The writer spent 13 days in the field during the month of November 1948, examining quarries and mapping in reconnaissance fashion areas lying between these widely separated quarries. Extensive detailed mapping, beyond the scope of this paper, would be required to

show all the complexities of the structure of the limestone, but examination of selected localities has demonstrated the value of such mapping as part of a program of exploration or development of limestone in this area. The total limestone reserves of commercial quality are large, but poor exposures and the discontinuity of the limestone make it difficult to estimate the amount available. In many parts of the zone even the appraisal of tonnages or quality of limestone in individual masses requires close attention to the complex geology and considerable exploration by trenching, drilling, and sampling.

The sketch map (pl. 1.) showing some of the major structures and the distribution of the limestone has been compiled with additions and modifications by the author, from the San Francisco and Santa Cruz folios of the U.S. Geological Survey, and from maps supplied by the Permanente Cement Company.

## INTRODUCTION

### Acknowledgments

Among those who generously supplied material for this report are John Zimmerman Jr., Permanente Cement Company geologist, and John G. Troster and Leonard V. Lombardi, geology students at Stanford University.

### Location and Accessibility

Discontinuous masses of limestone crop out along a northwest line bisecting the San Francisco Peninsula. From Calera Valley, San Mateo County, detached limestone masses extend southeastward along Cahil Ridge to a point west of Crystal Springs Lake. There the limestone masses and the rocks in which they occur are terminated by faulting and are overlapped by Cenozoic sediments. Limestone crops out again nearly 15 miles to the southeast on the summit of Black Mountain in Santa Clara County. From Black Mountain discontinuous masses of limestone extend southeastward through the quarries of the Permanente Cement Company and probably for tens of miles beyond.

The limestone belt is readily accessible from San Francisco, San Mateo, Redwood City, and other peninsular towns. A network of roads, both paved and gravel, makes access to most limestone localities relatively simple. A few areas, however, are somewhat isolated and can be reached only by dirt roads or by walking short distances. The quarries of the Permanente Cement Company, at the southeastern end of the limestone zone shown on plate 1, can be reached by a paved road. The Permanente cement plant, reported to be the largest in the world,<sup>1</sup> ships cement over a branch line of the Southern Pacific Railroad.

## GEOLOGY OF THE CALERA LIMESTONE

### Distribution

Although most limestone in central and northern California associated with Jurassic (?) Franciscan rocks has been correlated with the Calera limestone, the validity of such a correlation is still in some doubt. The Calera

<sup>1</sup> Logan, C. A., Limestone in California: California Jour. Mines and Geology, vol. 43, no. 3, p. 314, 1947.

\* Published by permission of the Director, U. S. Geological Survey. Manuscript submitted for publication December, 1949.

\*\* Geologist, U. S. Department of the Interior, Geological Survey.

limestone, herein described, is the limestone found at the type locality in Calera Valley, San Mateo County, and also includes the discontinuous outcrops of limestone that extend south and southeast from the type locality to the quarry of the Permanente Cement Company, Santa Clara County.

The limestone outcrops are surrounded by Franciscan graywacke, shale, red chert, porphyritic andesite, tuff and agglomerate, greenstone, and small amounts of schist. These rocks have been mapped previously as part of the Franciscan group of Jurassic (?) age, because lithologically they are typical of the Franciscan group as found elsewhere in California. The complexity of the structure and stratigraphy leaves this correlation open to question.

Individual masses of limestone are as much as a mile in length and range from 40 feet to a maximum of half a mile in width. The outcrop width does not everywhere represent the thickness of the limestone, for within individual masses the bedding is complexly folded and faulted. The thickness of the limestone is not uniform; at Rockaway quarry and at the Permanente quarries the thickness can be measured in hundreds of feet, whereas in other areas the thickness may be as little as 40 feet.

On the San Francisco Peninsula the limestone apparently is in one stratigraphic zone which is divided lithologically into at least two units. The upper unit is light buff to gray and locally has been named the "Upper Light" limestone. The unit stratigraphically beneath the light limestone is dark blue gray to black and is referred to locally as the "Blue" limestone.

#### Age

Fossil collections from the Calera limestone have been made from the type locality in San Mateo County, from outcrops along Cahil Ridge, and from the limestone in the quarries at Permanente. A collection of fossils from similar limestone outcrops 10 to 15 miles southeast of the Permanente Cement Company quarries has also been studied by Cushman and Todd,<sup>2</sup> who have tentatively assigned it to the Cretaceous. Foraminifera from the deposits of limestone at Permanente and Calera Valley have been assigned to the "Cretaceous" by Thalmann,<sup>3</sup> Pantin,<sup>4</sup> Miranda,<sup>5</sup> and others. The fossils were collected both from the limestone and from tuff beds interstratified with the limestone, and they consist of an assemblage of species of the genus *Globotruncana* and some species of *Globigerina*. This age assignment is contrary to an older well-entrenched opinion based mainly on work by Lawson<sup>6</sup> and by Branner,<sup>7</sup> that the Calera limestone is interstratified with Franciscan rocks and is therefore of probable Jurassic age.

<sup>2</sup> Cushman, J. A., and Todd, Ruth, A foraminiferal fauna from the New Almaden district, California: Cushman Lab. for Foram. Research, vol. 24, part 4, pp. 90-98, 1948.

<sup>3</sup> Thalmann, Hans, *Globotruncana* in the Franciscan limestone (abst): Geol. Soc. America Bull., vol. 54, no. 12, p. 1827, 1942.

<sup>4</sup> Pantin, J. H., Insoluble residues of the Calera limestone in Santa Clara County, California, Unpubl. Thesis (M.A.) Stanford Univ., 1946.

<sup>5</sup> Miranda, J. J., Insoluble residues of the Calera limestone from its type locality, Calera Valley, San Mateo County, California, Unpubl. Thesis (M.S.) Stanford Univ., 1946.

<sup>6</sup> Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 1914.

<sup>7</sup> Branner, J. C., Newson, J. F., and Arnold, Ralph, U. S. Geol. Survey Geol. Atlas, Santa Cruz folio (no. 163), 1909.

#### Relationship to Surrounding Rocks

The Calera limestone was defined by Lawson<sup>8</sup> in 1914 as a member of the Cahil sandstone, the basal formation of the Franciscan group. As described by Lawson from the type locality in Calera Valley, the limestone is approximately 60 feet thick and is underlain by 500 feet of sandstone and overlain by 2,000 feet of sandstone. In mapping the Santa Cruz quadrangle, Branner and others<sup>9</sup> considered the Calera limestone in that area to be part of an undifferentiated Franciscan mass that lies to the east of the San Andreas fault zone, where the limestone is surrounded by rocks typical of the Franciscan group, including sandstone, shale, red chert, porphyritic andesite, tuff, and agglomerate.

Lawson has shown that the Calera limestone, from Crystal Springs Lake northwestward, is associated with a group of rocks that includes the Cahil sandstone, serpentine, basalt, and diabase. All these rocks are shown on Lawson's map to lie within a fault block which is bounded on the west by the Pilarcitos fault and on the east by the San Andreas fault. The area between the two major faults is a nearly continuous zone of faulting and shearing. Recent road cuts and quarry excavations show that this block is laced with smaller faults and locally has been squeezed and deformed plastically.

Along the west slope of Cahil Ridge, outcrops are sparse and widely separated. Patches of limestone float can be found between outcrops, but most of the float in the intervening areas consists of sandstone and greenstone. The discontinuity of the limestone in other areas, such as the Ken Royce quarry in San Mateo County and in nearly all the limestone masses in Santa Clara County, strongly suggests that the masses along Cahil Ridge are fault slivers aligned along closely spaced and parallel northwest-trending faults. Parallel terraces along the west slope of the ridge may be due to high-angle faulting along shears parallel to the Pilarcitos fault zone. The terraces appear to be controlled by the difference in competence of the rocks that are on opposite sides of the shear zone, and by recent slumping of rock debris on the downhill side of the shear. The terraces, locally crushed and brecciated limestone, and distinct fault planes

<sup>8</sup> Lawson, A. C., op. cit.

<sup>9</sup> Branner, J. C., Newson, J. F., and Arnold, Ralph, op. cit.



FIGURE 1. West-dipping fault planes in fractured limestone, Hill Top quarry, San Mateo County.

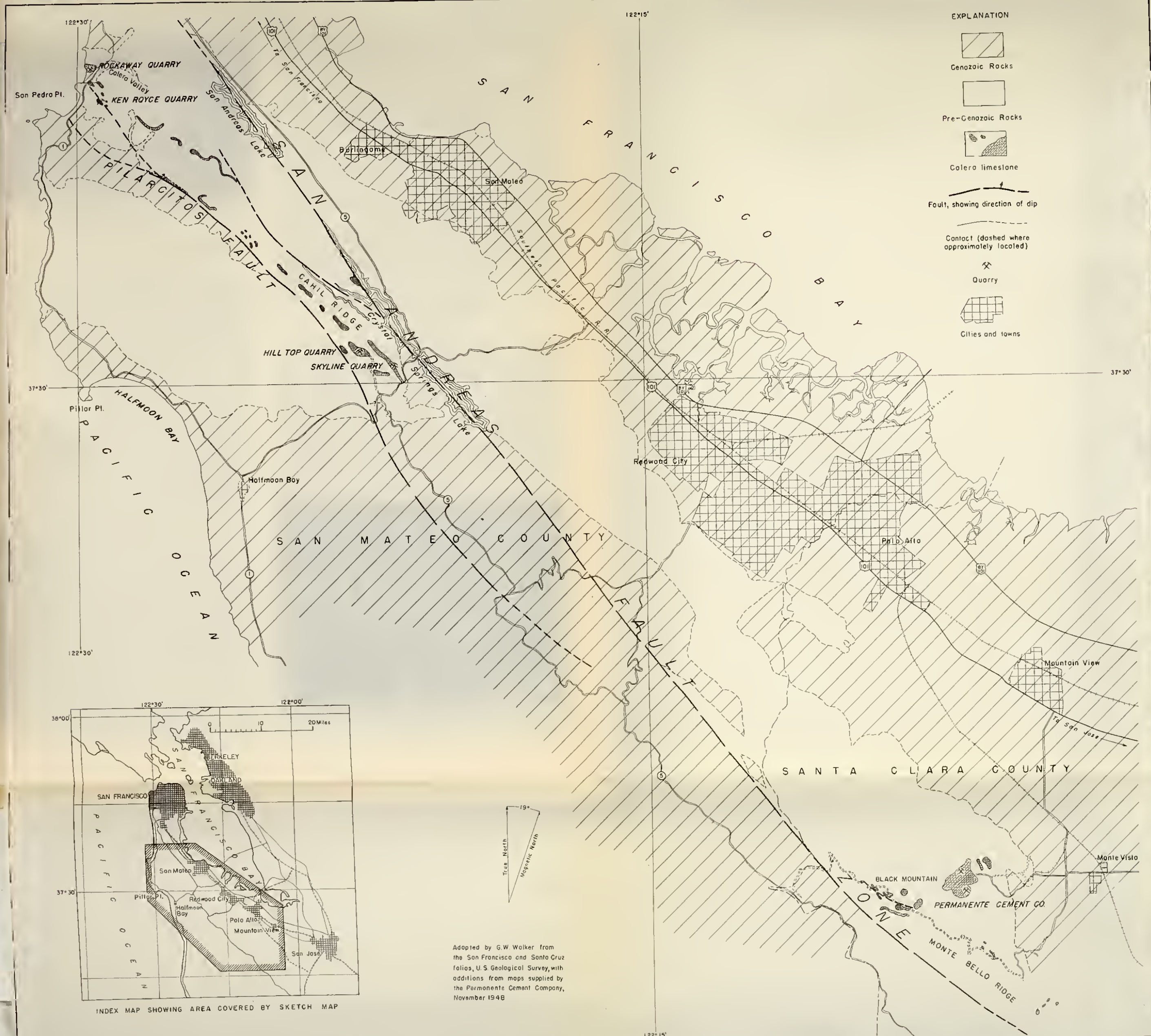






FIGURE 2. "Upper Light" limestone showing dark bands of chert interbedded with light-colored bands of limestone. Permanente Cement Company quarries.

in the Hill Top quarry (see fig. 1) are supporting evidence of a fault relationship between the limestone and the surrounding rocks.

Irregular joints and fractures, spaced from one-fourth inch to a foot apart, are characteristic of the Calera limestone throughout the length of the belt. Generally the "Blue" limestone shows greater deformation and more intense fracturing than the "Upper Light" limestone, though in the area between the Pilarcitos and San Andreas faults, both types of limestone are crushed and broken. Of the two joint systems which predominate, one is parallel to the major faulting of the area (N. 10°-40° W.) and the other trends N. 10°-40° E.

In the area near the Permanente Cement Company plant and at the summit of Black Mountain on Monte Bello Ridge, the rocks are strongly sheared and broken, but the intensity of deformation appears to be considerably less than that farther north. The location of many fault planes and gouge zones can only be inferred, for outcrops showing these zones are sparse or lacking. However, highly brecciated areas in the limestone suggest that the rocks have been subjected to considerable differential movement. Terraces along the west slope of Monte Bello Ridge are similar to those on Cahil Ridge, and are probably due to faults that are parallel to and immediately east of the main San Andreas fault zone.

The Calera limestone that occurs between the San Andreas and Pilarcitos faults has been broken into a series of fault slivers that apparently are suspended in sheared and plastically deformed sedimentary material and greenstone. At Rockaway quarry and at the Permanente quarries, a large mass of the Calera limestone has been folded, though little plastic deformation is evident, and faults and fractures cut through the limestone mass and bound it on both sides. At both these quarries small satellite limestone bodies are uncommon, whereas in the areas nearer the San Andreas fault zone the limestone bodies are small and have been widely distributed by more intense deformation and shearing.

Normal sedimentary contacts have not been identified as such between the Calera limestone and the Franciscan (?) rocks, and most exposed contacts, both at the top and the base of the limestone, are clearly faulted or are

so complex that they are not readily interpreted. Possible depositional contacts between the limestone and fine-grained sediments and greenstone are exposed at Ken Royce quarry, where bedding in the limestone is parallel to the bedding of the surrounding rocks, but even here a 3- to 4-foot zone of what may be fault gouge occurs along the contact.

Two possible explanations of the structural relationship of the Calera to the surrounding rocks are indicated by the faulted and sheared contacts between the Calera limestone and the surrounding sandstones and shales, and by the areal distribution of the limestone. Originally the Calera limestone may have been a continuous, or nearly continuous, unit interbedded in Franciscan-like rocks, or the lenticular limestone masses may all be fault slivers sheared into rocks of the Franciscan group. Evidence to solve this structural relationship is both obscure and contradictory; however, a fault relationship appears to be more plausible. The limestone occurs in an intensely deformed area, and where contacts are visible, individual limestone masses are bounded by faults. The rocks surrounding the limestone are typical of the Franciscan group, which is presumably of Jurassic (?) age. Within the mapped area it seems best, therefore, to consider the limestone masses as fault slivers.

#### PHYSICAL AND CHEMICAL PROPERTIES OF THE CALERA LIMESTONE

##### Lithology

At the Permanente Cement Company quarries, where the best exposures are available, the "Upper Light" limestone and the "Blue" limestone are distinct units. Two units with similar lithologic properties and fossil content have also been recognized in the limestone masses along Cahil Ridge and at Rockaway quarry in the northern part of the mapped area. At Permanente a third unit, the "Lower Light" limestone, is also present stratigraphically beneath the "Blue" limestone, but it is poorly exposed and little is known about it. Lithologic descriptions are here limited to the "Upper Light" limestone and the "Blue" limestone, because development has been almost exclusively in them. Only small quan-



FIGURE 3. "Blue" limestone showing thin discontinuous dark-colored bands of chert in gray limestone. Permanente Cement Company quarries.

titles of the "Lower Light" limestone have been utilized at the Permanente Cement Company.

The "Upper Light" limestone is light gray and contains numerous well-defined chert lenses and beds which form darker bands on weathered surfaces (fig. 2). Most of the limestone between the layers of chert is very finely crystalline and contains some foraminiferal remains. The beds, which range in thickness from 3 to 18 inches, have not been deformed as intensely as those of the "Blue" limestone; however, near faults the "Upper Light" limestone has been considerably drag-folded and crumpled.

The "Blue" limestone (fig. 3) has beds ranging in thickness from 1 inch to 8 inches, and the unit varies in lithology from the base to the top. Near the base finely crystalline limestone beds are intercalated with abundant chert lenses and layers. Upward the number of chert lenses diminish, and locally the top 15 or 20 feet is relatively free of siliceous material. The upper limestone beds in this sequence are medium to coarsely crystalline. Interbedded in the "Blue" limestone are layers of laminated tuffaceous debris a few inches to a few feet thick, and at many outcrops bedding-plane shearing has caused complex intermingling of tuffaceous fragments with fragments of oxidized and altered greenstone and sandstone. Weathered surfaces throughout the sequence are gray, whereas freshly broken surfaces are dark gray to black. A distinct petroleum-like odor is noticeable on freshly fractured surfaces, particularly in the upper part of the "Blue" limestone sequence. Locally, along bedding planes and near cross faults, the limestone is brecciated and the fragments are recemented by caliche and other carbonate material (fig. 4). In some places, incomplete recementation of the breccia has resulted in porous, spongelike masses of limestone. The "Blue" limestone is highly deformed and fractured and prominent drag folds occur near all but the smaller faults.

Locally, solutions have filled cavities with large calcite crystals and have introduced finely crystalline carbonate material into numerous fractures and joints. Solutions have also introduced silica which has replaced the limestone near larger chert lenses; and minute quartz grains, rhombohedral in shape and probably of second-

Table 1. Analyses of limestone from Permanente Cement Company quarries.

(Analyses by Permanente Cement Company Laboratory, Santa Clara County, California)

| Sample number                        | 1     | 2     | 3     |
|--------------------------------------|-------|-------|-------|
| CaO -----                            | 41.37 | 47.48 | 52.74 |
| MgO -----                            | 0.99  | 0.27  | 0.05  |
| Al <sub>2</sub> O <sub>3</sub> ----- | 2.82  | 1.12  | 0.66  |
| Fe <sub>2</sub> O <sub>3</sub> ----- | 0.66  | 0.54  | 0.32  |
| SiO <sub>2</sub> -----               | 22.82 | 12.86 | 4.18  |
| CaCO <sub>3</sub> -----              | 71.80 | 85.12 | 94.67 |

1. Typical analysis of the "Upper Light" limestone from Permanente quarries. The composition of this sample is similar to the average composition of all the "Upper Light" limestone found at Permanente. (Average CaCO<sub>3</sub> content of "Upper Light" limestone at Permanente is 70.8 percent.)
2. Analysis of the "Blue" limestone from Permanente quarries. This analysis is close to the average composition of all the "Blue" limestone at Permanente. (Average CaCO<sub>3</sub> content is 83.7 percent.)
3. Sample of high-grade "Blue" limestone from the quarries of the Permanente Cement Company.

ary origin, have been identified in the insoluble residues from the limestone.

#### Chemical Composition

The "Upper Light" limestone and the "Blue" limestone are very similar in chemical composition. Silica, in the form of chert lenses, is the most important impurity in both units; other adulterating materials are present in negligible quantities. The percentage of SiO<sub>2</sub> varies not only from outcrop to outcrop within the belt, but also from one stratigraphic horizon to another within the limestone units. Limestone beds between layers of chert have a calcium carbonate content as great as 97 percent. Small quantities of MgO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> are the only impurities (tables 1 and 2). The "Blue" limestone generally contains a higher ratio of CaCO<sub>3</sub> to SiO<sub>2</sub> than the "Upper" or "Lower Light" limestone. The purest beds are near the top of the "Blue" limestone where chert lenses are scarce or absent, and the CaCO<sub>3</sub> content approaches 97 percent of the rock analyzed. The amount of carbonaceous material in the "Blue" limestone was not determined, though the petroliferous odor on fresh surfaces indicates the presence of this material.

A report by Eckel<sup>10</sup> includes a description of the Calera limestone, some estimates of its economic value, and quotes several analyses of the limestone.

#### ECONOMIC EVALUATION

Exploitation of the Calera limestone was started, for use in the beet sugar industry, about 1907 at Rockaway quarry in the canyon immediately south of the Permanente Cement Company plant. Prior to this time some lime from Santa Clara County was burned for use in the building industry of San Francisco. In the early days of development, quarrying proved profitable only at favorable localities where the limestone was near the maximum thickness and where the chert content was low. This resulted in selective quarrying in some areas of the upper part of the "Blue" limestone beds where the CaCO<sub>3</sub> content was above 90 percent. The growing needs of the building industry and a greatly increased demand for cement products have made it possible to utilize large tonnages of lower-grade limestone available from the lower part of the "Blue" beds and from the "Upper Light" beds. In 1948 the "Upper Light," the "Blue,"

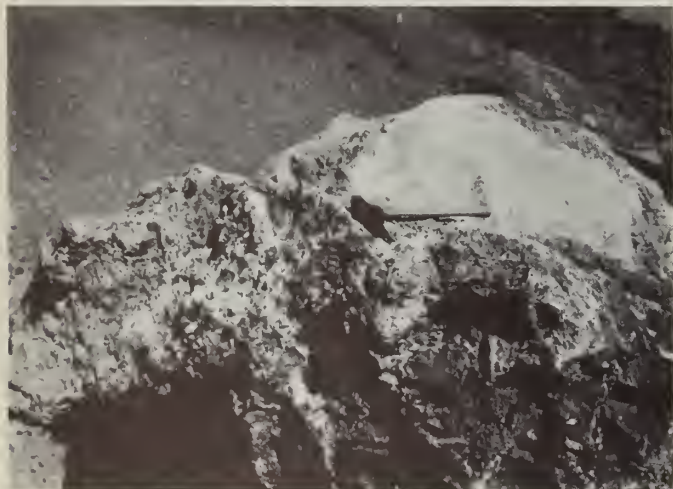


FIGURE 4. Brecciated "Blue" limestone cemented by caliche from quarries of the Permanente Cement Company.

<sup>10</sup> Eckel, Edwin C., Limestone deposits of the San Francisco region: California Div. Mines Rept. 29, pp. 348-361, 1933.

Table 2. Analyses of the Calera limestone from deposits other than those of the Permanente Cement Company.

(P. T. Bee, Chief Chemist, Abbot A. Hanks, Inc.,  
San Francisco, California)

| Sample number                        | 1     | 2     | 3     | 4     | 5     |
|--------------------------------------|-------|-------|-------|-------|-------|
| CaO -----                            | 44.81 | 48.73 | 35.64 | 44.96 | 43.76 |
| MgO -----                            | 0.31  | 0.32  | 0.58  | 0.36  | 0.29  |
| Al <sub>2</sub> O <sub>3</sub> ----- | 1.51  | 0.98  | 2.26  | 2.23  | 1.95  |
| Fe <sub>2</sub> O <sub>3</sub> ----- | 0.42  | 0.26  | 0.34  | 0.58  | 0.33  |
| SiO <sub>2</sub> -----               | 16.73 | 10.85 | 32.23 | 15.59 | 18.74 |
| CaCO <sub>3</sub> -----              | 80.02 | 87.01 | 63.65 | 80.29 | 78.15 |

1. Sample from the dark-blue limestone at Rockaway quarry, San Mateo County, California. Sample taken across a 40-foot stratigraphic section which represents only a part of the total thickness of the "Blue" limestone in the quarry.

2. Sample representing a 35-foot section in the "Upper Light" limestone from Rockaway quarry.

3. Sample of limestone taken from stock pile at Ken Royce quarry, San Mateo County, California.

4. Sample representing a 35-foot stratigraphic section of "Blue" limestone from Hill Top quarry, San Mateo County, California. Total thickness of limestone exposed in the quarry is approximately 55 feet.

5. Composite sample representing both "Blue" and "Upper Light" limestone taken across the face of Skyline quarry. Total thickness of limestone not determined, though sample represents a 70-foot part of the stratigraphic section.

and, at the Permanente Cement Company quarries, some "Lower Light" limestone was being quarried for the manufacture of cement, concrete aggregate, and road metal. For these products the CaCO<sub>3</sub> content can be well below 90 percent, and by "sweetening" low-grade rock, nearly all the limestone can be quarried profitably. The factors governing exploitation of the Calera limestone are the size of the individual limestone mass, the amount of shattering and later infiltration of fault gouge and deformed rock, the thickness of the overburden, and to a limited extent, the accessibility of the limestone masses.

At the plant of the Permanente Cement Company, where the limestone is used almost exclusively for the manufacture of cement, 4,500 to 5,000 tons of Calera limestone is quarried during an 8-hour working day. From this nearly 15,000 barrels of cement is produced daily. Clay derived from altered and weathered andesite and sediments is found adjacent to the limestone mass and is used in the cement-manufacturing process. Gypsum, necessary in the production of the cement, is shipped in from outside localities. Limestone that falls below specifications for the manufacture of cement is utilized for concrete aggregate and road metal. During the past few years some high-grade limestone has been sold for sugar refining.

The companies quarrying limestone in the northern part of the mapped area utilize the limestone entirely for



FIGURE 6. Upper quarries of the Permanente Cement Company.

concrete aggregate, concrete sand, and as road metal. At times, small quantities of finely crushed limestone have been sold as poultry grits. Figures for the production from the Ken Royce and Hill Top quarries are incomplete. In November 1948 these two quarries were temporarily shut down. At the Ken Royce quarry, however, a stock pile of aggregate rock was being shipped. According to the operators, production at the Rockaway quarry amounts to 700 to 800 tons of concrete aggregate and 200 to 300 tons of road metal, a total of approximately 1,000 tons per day. Production at the Skyline quarry is approximately 1,500 tons per day.

In most areas that are being developed power shovels and bulldozers remove nearly all the fractured limestone and little blasting is necessary. The limestone is generally so highly fractured that crushing to sizes suitable for aggregate is necessary only for the coarser fragments retained after screening. In many areas the fragments average one-half to three-fourths inch in greatest dimension. At the Permanente Cement Company, however, the type of quarrying used requires more extensive blasting. Charges are placed so as to cut large tonnages of rock from the high and precipitous quarry faces (figs. 5 and 6). To reduce this material to sizes suitable for calcining in the kilns, more extensive crushing and grinding is also necessary.

Most of the limestone masses, with the exception of those at the Permanente Cement Company, Rockaway, Skyline, and possibly Hill Top quarries, appear to be either too discontinuous or too thin for profitable exploitation. The only unworked area that shows some promise of profitable development is near the summit of Black Mountain. Here the limestone crops out over a fairly large area and some of the limestone masses appear to be continuous. However, Permanente Cement Company, which controls this area, has drilled the limestone and has considered the area unsuitable for development at the present time. The finding of additional sites favorable for new quarries is greatly hindered by poor and widely spaced exposures. The soil cover is generally thick, ranging from 5 to 30 feet or more; the cover of vegetation is heavy, so many large limestone masses may be hidden.

Future detailed mapping and reconnaissance magnetic surveys may indicate areas underlain by sufficiently



FIGURE 5. Upper quarries of the Permanente Cement Company.

large masses of limestone to make development feasible. Experimental surveys made with a dip needle suggested differences in the magnetic properties of the limestone and

the surrounding rocks. Cahil Ridge is perhaps the most suitable area for exploration by trenching, drilling, magnetic surveys, and sampling.

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